PROTECTION OF CRITICAL ASSETS FROM CONSTRUCTION VIBRATION: FIELD TESTS, PREDICTION, AND CONTROL

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1 Introduction

This paper presents the results from vibration testing and modelling conducted during the design of a major hospital complex expansion adjacent to a research facility. The expansion will include construction of several multi-storey buildings with shoring, construction of raft slabs and Franki pile-supported slabs, and large-scale compaction. The research facility houses many sensitive laboratory equipment as well as a vivarium at basement level. Protection of research assets is a major concern during construction as ground-borne vibrations can affect performance of sensitive equipment, disrupt long-term experiments (e.g., cell culture development), and impact the health of the animals.

As Vibration Consultants on the project, the authors were responsible for developing vibration control specifications to ensure appropriate protection of the research facility and surrounding land uses during demolition and construction. This included development of a construction vibration model to predict vibration levels during various demolition and construction activities based on coordinated testing at the site.

2 Coordinated site testing

Two separate sets of construction tests were carried out to determine site specific ground propagation properties, building attenuation characteristics, and to obtain qualitative feedback from users during tests.

2.1 Excavator and plate compactor

The first phase of testing was carried out using an excavator armed with a plate compactor to apply impacts and vibratory compaction to the ground at the surface and at a depth corresponding to the depth of new building foundations.

Vibration monitors were installed at six locations within the research facility and at the base of the building foundation as shown in Figure 1.

2.2 Pile driving

Preliminary modelling was conducted following the first phase of tests to establish potential impacts of Franki Piling. Model parameters were extracted from the excavator testing as well as historical measurements of Franki pile installations at other sites. The results indicated that the installation of Franki piles had the potential to significantly disrupt experiments and animals in the research building, in addition to potential cosmetic damage to residential buildings close to the pile locations.

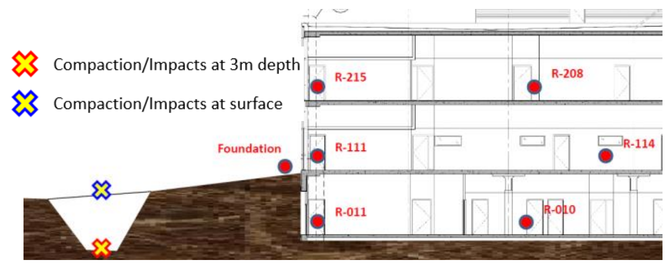

Figure 1: Building section showing relative vibration monitor locations during excavator testing.

Vibration measurements on the ground surface were also conducted using 6 monitors spaced out to 100 m with both impacts and vibratory compaction measurements at the ground surface and at a depth of approximately 3 m.

To accurately evaluate the risk of the pile driving activity it was determined that test piles on site would be required. Two test piles were installed using a 7,000 lb hammer at varying drop heights increasing from 5 ft to 20 ft. Vibration monitors were installed on the ground surface near the piling rig, within the research facility and hospital, and at the foundations of surrounding residential buildings.

Results from the Franki pile tests were then used to refine the construction vibration model developed with updated parameters related to large impact events.

3 Site vibration model

Results from the site tests were used to develop a model to evaluate vibration impacts from a range of construction equipment and activities. The model was defined as follows:

$$V_r = PPV_s\, D^{\alpha} + CL + \beta d$$

V_r = predicted vibration level;
$PPV_s\, D^{\alpha}$ = transmission of vibrations in the ground;
CL = attenuation by the building foundation; and,
βd = transmission of vibration within the building.
Where:
PPV_s = construction equipment source vibration level;
D = distance between equipment and building foundation;
α = ground vibration decay factor;
CL = foundation attenuation factor;
β = structural floor decay factor; and,
d = distance to interior space from foundation wall.

Inputs to the model were calculated from the measurement data. Plots of ground propagation and building

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transmission used to generate input parameters are provided in Figure 2 and 3, respectively.

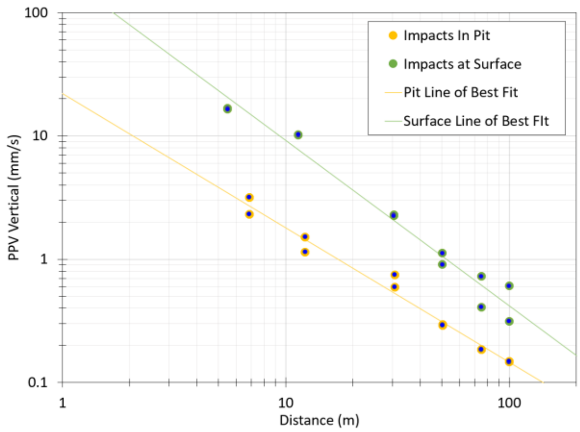

Figure 2: PVS ground propagation for excavator bucket impacts at surface and at depth of building foundations.

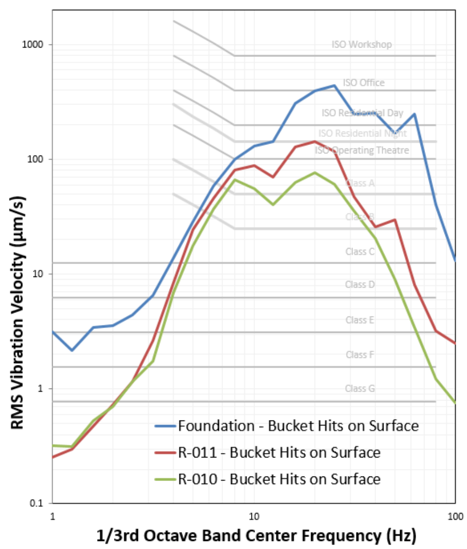

Figure 3: Vertical building transmission from excavator bucket hits at ground surface. See Figure 1 for measurement locations.

The model also includes vibration source type (impact vs. steady-state) and source vibration frequency. Permissible set-backs could then be calculated for each type of equipment and operating parameters.

4 Design criteria and verification

Construction impacts to be addressed included:

- disturbance to research animals and biological experiments;
- operation of sensitive equipment (e.g. microscopy);
- occupant comfort; and,
- cosmetic structural damage.

Specific criteria were developed for each of these receivers to ensure adequate protection of all assets. A summary of the generic vibration criteria selected is included in Table 1 for reference [1, 2].

Table 1: Selected vibration criteria.

Receiver	Criteria	Vibration Level (RMS)	Basis
Research Facility	Max	**ISO-Operating Theatre** 0.1 mm/s	Protection of animals
	Preferred	**Class-B** 0.025 mm/s	Operation of equipment
Residences	Max	25 mm/s	Cosmetic damage
	Preferred	**ISO-Residential Day** 0.2 mm/s	Human comfort
Existing Hospital	Max	**ISO- Residential Night** 0.140 mm/s	Patient comfort
	Preferred	**Class-B** 0.025 mm/s	Operation of equipment

Protection of animals in the research facility was deemed the most critical and governed set-back recommendations. As such, verifying these criteria were appropriately selected was important to ensure the restrictions placed on the construction equipment were not overly restrictive.

During Franki pile testing vibration monitors within the animal research areas recorded a peak vibration velocity of 0.75 mm/s which corresponded to an RMS velocity of 0.1 mm/s. Spectrally these measurements were in agreement with the ISO-Operating Theatre criteria selected for the animal research areas. During tests staff within the animal research areas did not perceive any vibration impacts and all activities were conducted uninterrupted including surgery.

5 Vibration control during construction

While the construction vibration model did include site specific parameters and was verified by on site testing and measurements, a vibration monitoring protocol was required to guide the construction team in the protection of critical assets. Safe operating set-backs were provided as a general recommendation; however, these requirements may not be followed on site and cannot completely cover all possible activities and pieces of equipment.

To provide the required level of protection a vibration monitoring protocol was developed which focussed on the research facility and animal protection. This included monitor locations, alarm and trigger levels to change work, and stop-work conditions.

Over the course of the demolition and construction activities measurements collected were continually analyzed to verify the vibration model and make any updates to refine control requirements as appropriate.

References

[1] Amick, H, et al. "Evolving Criteria for Research Facilities: I Vibration." Proceedings of SPIE Conference 5933, 2005.

[2] Carman, Richard, et al. "Vibration Effects on Laboratory Mice during Building Construction." The Journal of the Acoustical Society of America, June 2008, doi:10.1121/1.2935010.